Very Shallow Water Mine Vulnerability

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LONG TERM GOALS

The Very Shallow Water Mine Vulnerability (VSWMV) Task is intended to provide reliable guidance to the explosive ordnance disposal (EOD) community regarding small charge conditions needed for reliable explosive neutralization of specific types of very shallow water mines. The guidance is based upon both scientific expertise and experimental test results. A long-range goal is to apply the methodology to current and future threats, and to maintain and update recommended neutralization procedures in accord with an expanding knowledge base.

OBJECTIVES

The specific objectives of the task are the following: For each of ten mines specified by PMS-EOD, the Indian Head Division of the Naval Surface Warfare Center (IHDNSWC) is to (1) estimate C-4 charge weights needed to produce both detonation and neutralization responses with probability 0.9 and confidence limit 0.8 when placed at distances of two, three, and four feet from the mine fuze; (2) estimate the distances from the mine fuze that a 2-lb. C-4 charge will produce both detonation and neutralization responses with probability 0.9 and confidence limit 0.8; and (3) estimate the distances from the mine case at which a single 10-lb. SABRE charge will produce both detonation and neutralization responses with probability 0.9 and confidence limit 0.8. For each mine and response level, rigorously specifying the band of uncertainty on the conditions for achieving a high probability of mine destruction is the central purpose of this work.

APPROACH

This problem involves both the engineering aspects of mine response to explosive loads and mathematical statistics. For each of the objectives, the principle task is to characterize the relationship between mine neutralization probability and charge weight or charge position. An approach based upon Bayesian statistics has been adopted wherein unknowns, such as probabilities and probability percentiles, are regarded as random variables. The task involves the characterization and quantification of their associated distributions. Usually, the main concern is with distributions of neutralization probability. But the above objectives principally concern the uncertainty of stating the charge weight (with a fixed standoff) or standoff (with a fixed charge weight) that is associated with a 90 percent probability of neutralization, i.e., the 90th percentiles of neutralization probability. Under the Bayesian approach, the uncertainty of knowing the 90th percentile is specified in terms of an interval that expresses the width of the associated distribution, i.e., an interval on scales of charge weight or charge standoff. The interval chosen is the called the 80 percent coverage interval to conform to the more classical statistical notion of 80 percent confidence. The widths of the coverage intervals depend upon the amounts of test data available and, thus, also serve to indicate the degree of improvement that could result from additional testing of the mine's response to explosive loads. A systematic approach for quantifying these intervals has been devised. It is similar for each mine and response class and can be summarized in four steps, (1) Development of Prior Distributions, (2) Collection of Bulk Charge Test Data, (3) Development of Posterior Distributions, and (4) Development of Interval Estimates.

Step (1) is performed by a panel of experts on the vulnerability of mines to explosive loads. For each mine, each expert selects a load scale, such as energy flux density E, and expresses his uncertainty regarding the probability of neutralization associated with, say, each value of E, by indicating the 10^{th}, 50^{th} and 90^{th} percentiles of the distribution. When connected together these percentile points fall along 10^{th}, 50^{th} and 90^{th} percentile curves that are functions of E. Examples of such percentile curves are illustrated in Figure 1 by the dashed lines.

The individual opinions are then combined using DeGroot's method[1] to form a joint expression of the panel opinion. Opinions are given without knowledge of (or regard for, if known) the bulk charge test data collected in step (2). But they may be based upon data from different, but related, mine neutralization tests, such as tests that employ multiple charge arrays, detonating cords, or bulk charge tests against mines of different types. Prior opinions are also based upon knowledge of the mine designs and an understanding of the physics of structural responses to dynamic loads.

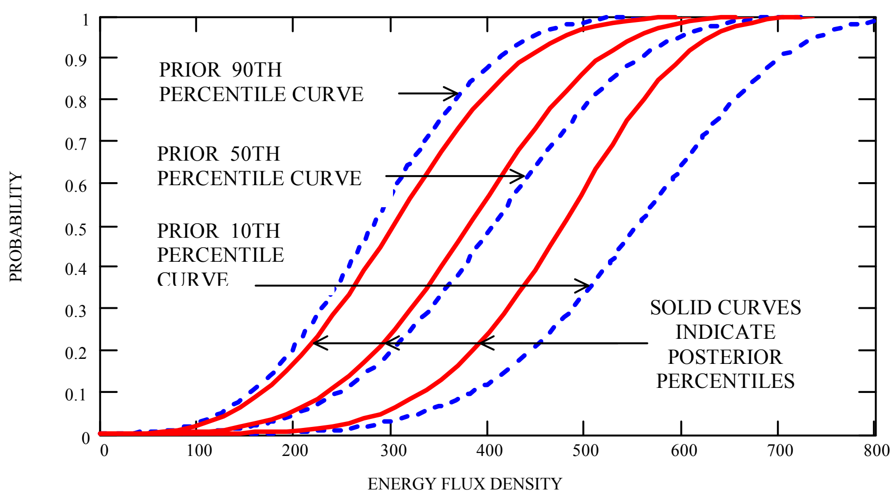

Figure 1. Probability Percentile Curves Versus Energy Flux

The posterior distribution of mine neutralization probability as a function of load is determined (step 3) by combining the available bulk charge test data with the prior distribution in a manner that accords with Bayes' Law. This is done in NSWC IHD's nonparametric Bayesian regression code MBR. As its output, MBR produces a set of updated 10^{th}, 50^{th}, and 90^{th} percentile curves like the solid curves of Figure 1, that characterize the posterior probability distributions as functions of the loading quantity. The narrowing of the spacings between the posterior curves signifies a reduction in the uncertainty of the response probability due to inclusion of the test data.

Distributions of neutralization probability as functions of charge weight and standoff are obtained (step 4) by integrating MBR's posterior distributions, that are conditional on load, with the probability of getting a particular load given particular values of charge weight and standoff. The latter depend on the estimated accuracy of the algorithm used to calculate the load. Figure 2 shows 10th, 50th, and 90th percentiles of the resulting probability distributions as functions of bulk charge weight for a fixed value of standoff. The 80-percent coverage interval for the charge weight associated with a 90-percent neutralization probability at this range is obtained as illustrated in Figure 2. This subtle step makes use of a relationship between uncertainty of probability and uncertainty of probability percentile that was proved in this work.

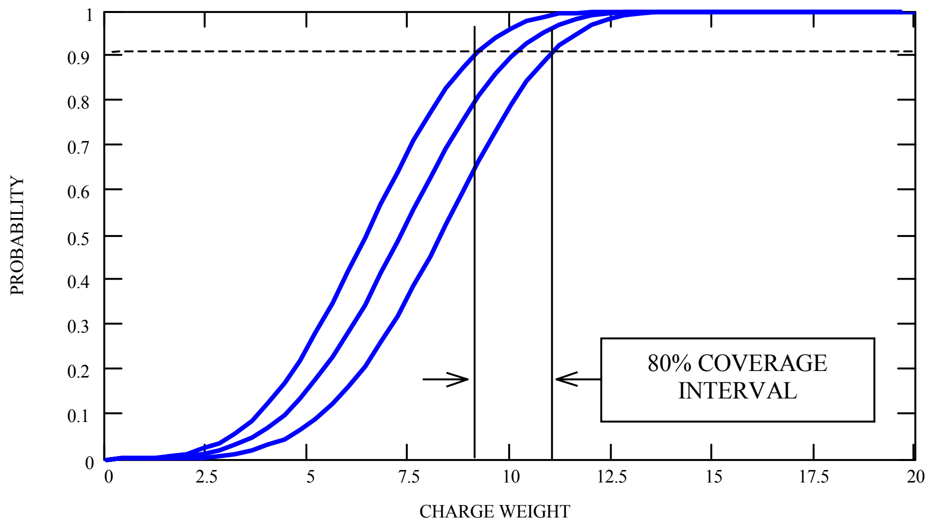

Figure 2. Probability Percentile Curves Versus Charge Weight

WORK COMPLETED

The task was completed and documented[2] during this reporting period. Significant FY2000 accomplishments included (1) the completion of mine vulnerability assessments for all ten mines by each member of the panel of mine vulnerability experts assembled for this task, (2) the development of the appropriate Bayesian statistical theory and computational programs required for the analysis of the test data and expert opinion, (3) the development of consensus prior percentile distributions and coverage intervals for all mines, (4) the development of consensus posterior distributions and coverage intervals for those mines having available experimental test data, and (5) completion of the report with specific discussions of each mine.

RESULTS

A practical and coherent methodology for modeling and predicting the vulnerabilities of mines to explosive loads has been achieved. The damage mechanisms associated with each of the ten mines of interest were determined and were given consideration by each panelist in making their prior vulnerability assessments. Mathematical expressions for the posterior distributions of the 90th percentiles of the varied test condition (charge weight or standoff) were developed based on Bayesian statistical principles in terms of the panelists prior distributions (conditional on a loading quantity), the distribution of the loading quantity (conditional on the test conditions), and the binary (survive/fail) test results. Separate expressions were obtained for the cases where measurements of the loading quantity (e.g., energy flux density) had been made during explosive mine neutralization tests and where they had not. Although the latter was not the case for the current analyses, the equation obtained for use when measurements are missing significantly extends the methodology. The added complexity and loss of accuracy introduced when measurements of the loading quantity are not available provide theoretical justifications for including such measurements as part of the mine vulnerability testing programs. In the current analysis, the results for those mines with both loading quantity measurements and response data available demonstrated the improvement that can be realized by combining mine vulnerability test results with the expert opinions. These showed that the amount of improvement was sensitive to the conditions under which the mine vulnerability tests were conducted. A case of mine overkill, for example, provided almost no improvement because the data fell outside the region of uncertainty. Other cases having data within the uncertain region showed subtle differences. Thus, the methodology is not only useful for performing retrospective analyses of mine vulnerability tests, it is also a very useful tool for planning future tests and for determining optimal testing conditions.

Coverage intervals were provided for all ten mines and for all task objectives. These were used to recommend small bulk-charge neutralization procedures, based on the currently available information, and also to rank the mines in terms of interval widths. From the ranking it is possible to identify those mines for which future programs of mine vulnerability testing should be the most beneficial. In selecting the mines for future testing, consideration should also be given to the military threats presented by the mines. A systematic, quantified approach to this decision process is possible with these results, but was not included as part of this study. Specific discussions, for each mine, of the mechanisms for mine damage by underwater explosions were included in the report and should be of interest to EOD personnel. Some previous methods of reporting the vulnerabilities of mines to explosive loads were critically reviewed. Suggestions are given for increasing the efficiency of future expert-guided mine vulnerability analyses of a similar nature.

IMPACT/APPLICATION

The mine vulnerability assessments developed in this task provide critically required data for developing weapons and tactics for use by the VSW Detachment. The vulnerability predictions developed in this task will be very useful in planning field tests and exercises by the VSW Detachment. The methods developed in this task also will also be valuable in applications to other mine warfare environments, in addition to the VSW regime, because they allow a rational prediction of the vulnerability of mines even when few or no examples are available for testing. Such is often the case for deeper water mines. The methodology developed provides a scientific foundation for the development of future mine vulnerability assessment technology.

TRANSITIONS

This work represents a model for future mine vulnerability assessments and provides a means for systematically improving upon and updating mine neutralization procedures, which can be used in all water depth regimes. The predictions of the vulnerability of the specific mines addressed in this study have been transitioned to PMS-EOD for their use.

RELATED PROJECTS

This task directly supports the PMS-EOD task of developing weapons and equipment for the VSW Detachment. The closely related Mine Vulnerability Task concerns the effectiveness of mine clearance systems in the surf zone against a variety of mine threats. Data from the Mine Vulnerability Task has been used directly in the present effort.

REFERENCES

1. Morris H., DeGroot, 1974. Reaching a Consensus*, Journal of the American Statistical Association*, Vol. 69, pp 118-121, March.

2. W.W. McDonald, 2000. Vulnerability of Ten Very Shallow Water Mines to Small Bulk-Charge Explosions Using a New Assessment Methodology, IHTR 2274, Indian Head Division, Naval Surface Warfare Center, 1 July, SECRET.